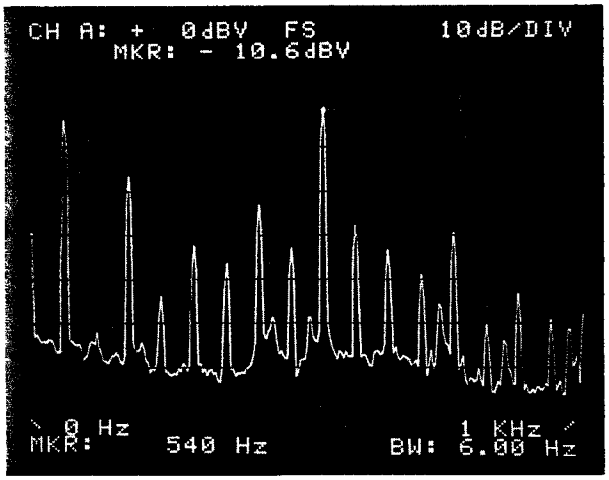
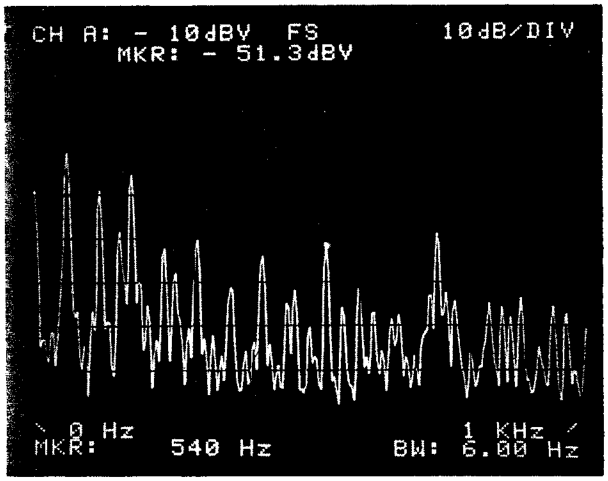
E_z

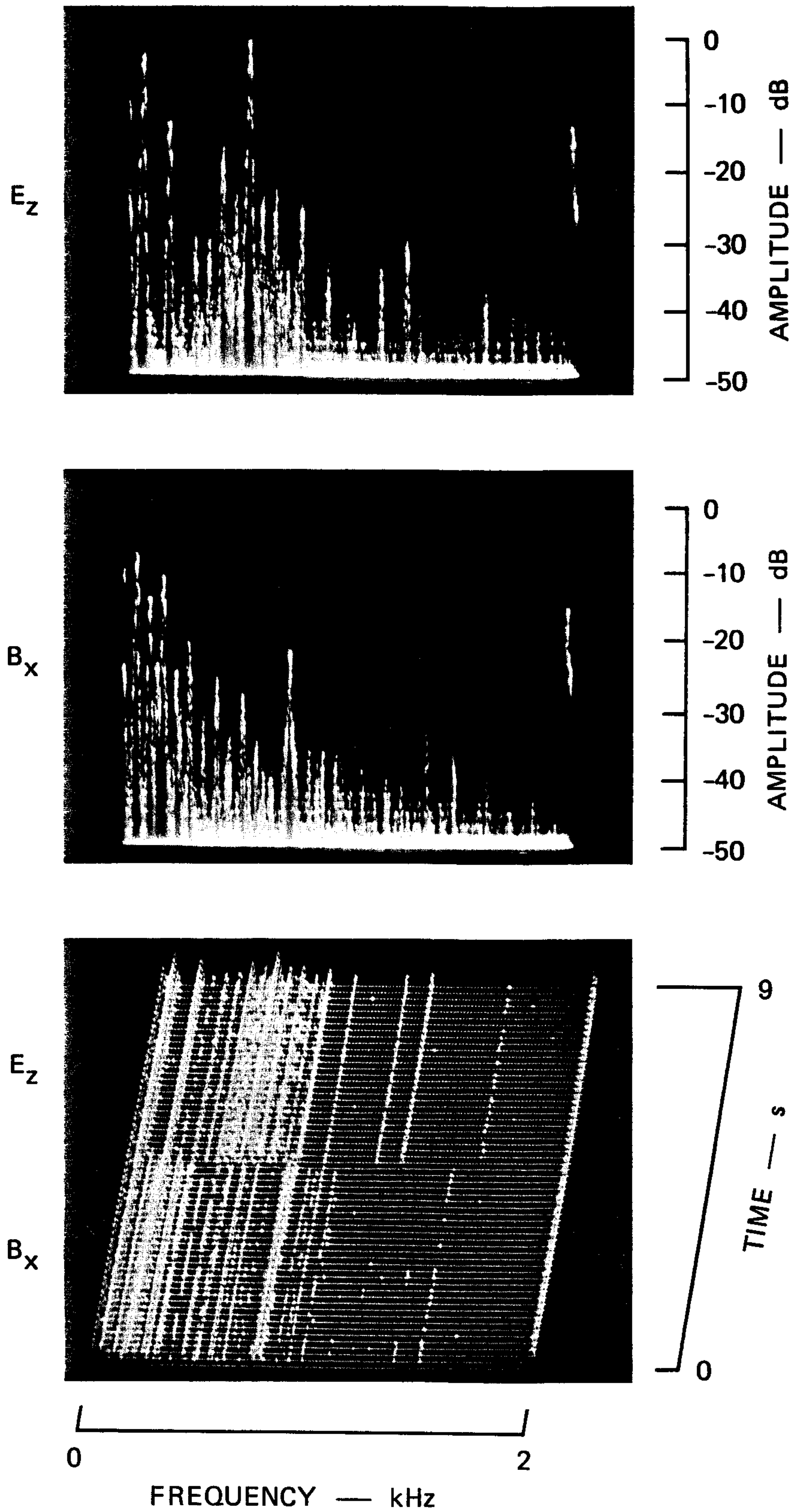


B_x



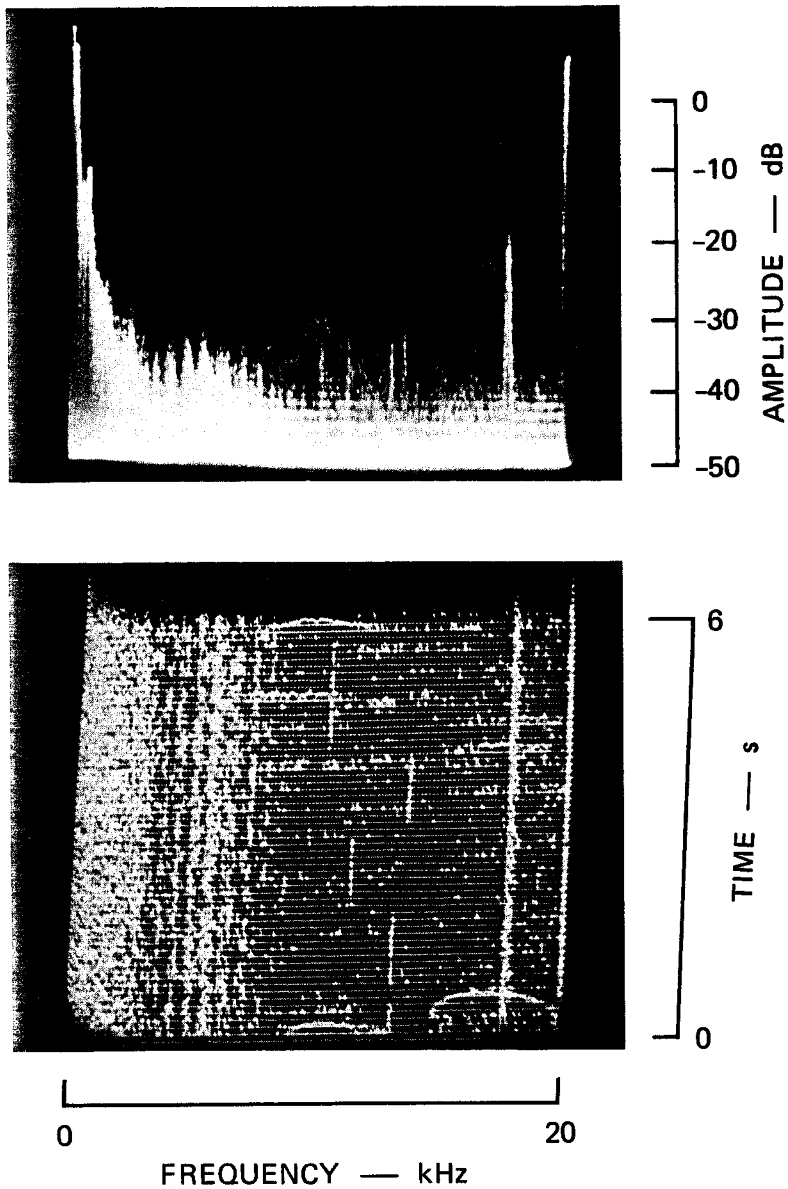
1256, 1305, 9-16-82
WPP, WV, E, UNIVERSAL WELDING
E_z, + 50, rms 16, H
B_x, + 40, rms 16, H
(Amplitude scale must be correctea using Figure A-1 for the E field and Figure A-2 for the B field)

FIGURE 6 VOLTAGE AND CURRENT HARMONICS, 0 TO 1 kHz, UNIVERSAL WELDING



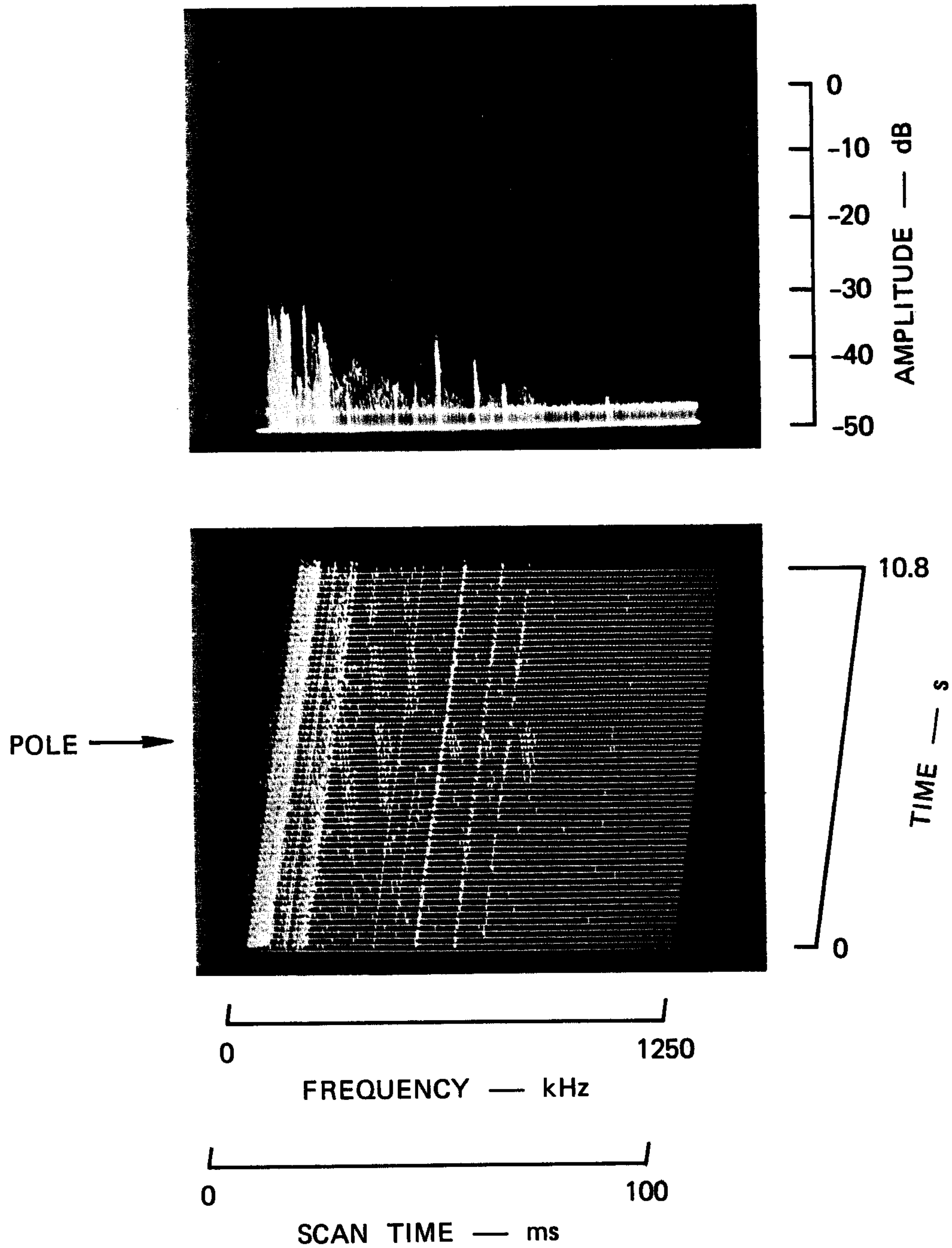
1238, 9-16-82
WPP, WV, E,
UNIVERSAL WELDING
E_z, + 50, -20, + 10
B_x, + 30, 0, + 10
0, 2, T2, X 3
(Amplitude scale must be corrected using Figure A-1 for the E field and Figure A-2 for the B field)

FIGURE 7 VOLTAGE AND CURRENT HARMONICS, 0 TO 2 kHz, UNIVERSAL WELDING



1305, 9-16-82
WPP, WV, E, UNIVERSAL WELDING
B_X, + 40, 0, + 10
0, 20, T20, × 2
(Amplitude scale must be corrected using Figure A-2)

FIGURE 9 CONTROL TONES ON UNIVERSAL WELDING DROP



1152, 9-16-82
WPP, WV, E, POLE 1 BEYOND RR
E_z, 1 m, + 20, 0, - 20
0-1250 MHz, 1250 MHz, 300 kHz, 100 ms

FIGURE 10 GAP NOISE ON 12-kV LINE

IV SUMMARY

The primary objective of the measurements, that of relating ultrasonic noise and radio noise from a capacitor suspected as defective, was not achieved. However, a number of secondary findings and conclusions were reached. These are:

(a) The two capacitor banks examined had previously been identified by Westinghouse as producing positive ultrasonic results. These capacitor banks were subjected to unusually high 9th harmonic voltage and current conditions. At this frequency, the capacitor impedance was sufficiently low that significant 9th harmonic current would flow. Also, the capacitors were subjected to intermittent high-current bursts, with spectral energy centered at 10 kHz. These two conditions would produce some dielectric stress and could be a factor in capacitor life.

(b) The brief one-day measurement and the small number of capacitors examined (one bank) were an inadequate sample to investigate properly a possible relationship between ultrasonic noise and radio noise from capacitors suspected of failing.

(c) Because gap noise was identified on the poles containing capacitor banks and on other nearby poles, any practical investigation of the relationship between ultrasonic noise and radio noise must be made with instrumentation capable of distinguishing between the various kinds of radio noise. Measurements with standard radio-noise equipment would not be sufficient to identify a specific noise originating from a capacitor failure mechanism.

Appendix

DESCRIPTION OF SENSORS

The E-field sensor used in the distribution-line measurement of electric fields consists of a 1-m-diameter circular set of aluminum plates, spaced 5 cm, with one plate acting as the ground plane. The plate antenna is broadband, with flat frequency response over the range 30 Hz to 500 kHz. A line driver with unity gain above 6 kHz and 100-to-1 attenuation (40 dB) at 60 Hz was used in conjunction with the flat plate antenna to drive a 100-ft coaxial cable running to the instrumentation van. Figure A-1 displays the attenuation characteristics of the line driver.

The B-field sensor used in distribution-line measurement of magnetic fields is a broadband, ferrite, loopstick-type device with 60-Hz de-emphasis, and flat response to constant-strength incident fields from about 1 kHz to 300 kHz. Figure A-2 can be used to determine the amount of attenuation below 1 kHz.

All sensors and sensor-probe line drivers were battery powered to avoid supply, ground loop problems at low signal levels.

To determine the signal level being sensed, add the level being measured in dBV to the sensor conversion factor, and the amount of amplitude correction at a given frequency from Figures A-1 or A-2 as appropriate.

- Large plate antenna--46.6 dBV/m
- Ferrite loopstick sensor--107 dB

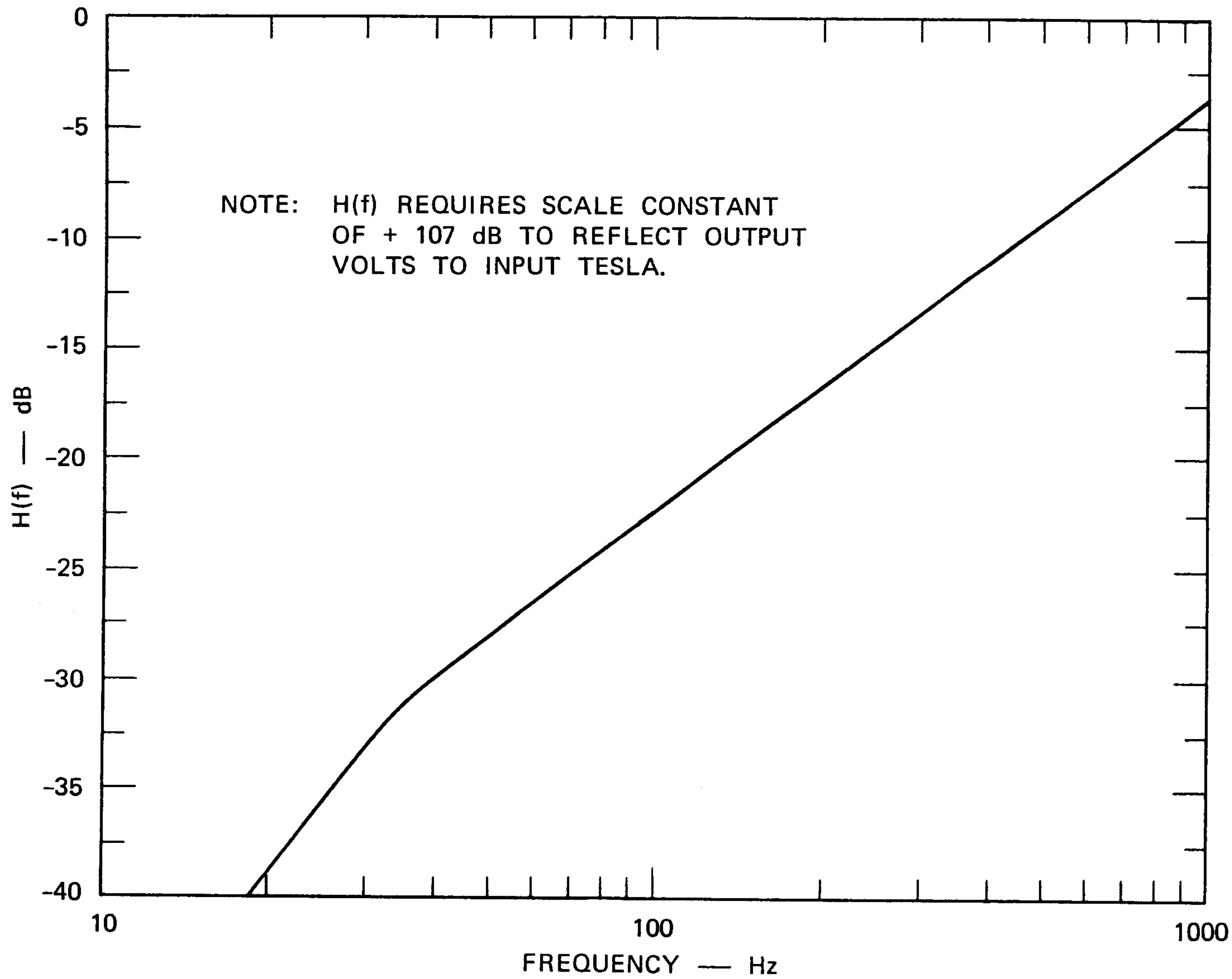


FIGURE A-2 MAGNETIC FIELD SENSOR DEEMPHASIS VERSUS FREQUENCY

SRI International

Progress Report *9 May 1983*

RESIDENTIAL ELECTRICAL NOISE MEASUREMENTS

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EPRI Project RP2017-1

SRI Project 3564

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General Comments

The house measurements were started during April 1983. Measurements for one house have been completed, and partial data have been obtained from a second house. The early days of measurement were spent establishing measurement procedures and constructing the fixtures needed to couple SRI instrumentation into appliance wiring efficiently. These fixtures were tested, and all probes were calibrated. Additional minor delays were encountered because of the unusual data obtained from initial measurements. Stopping to analyze the data was necessary before proceeding with a measurement sequence to ensure that unusual data were fully understood. Even with the delays, progress has been made, and some interesting results have been obtained.

The ambient voltage harmonic levels propagated from the distribution line into a home are much higher than anticipated. Ambient voltage harmonics are higher than the voltage harmonics generated by many appliances. Appliances generally produce pronounced current harmonics and current noise, while ambient current harmonics from the distribution line are low.

Some television sets produce high voltage and current harmonics, noise, and undesired signals on the house wiring while other television sets do not produce significant noise and signals. As additional data are obtained, an effort will be made to categorize television sets according to produced harmonics and noise. With a sufficiently large sample size, this categorization may reveal correlations between noise and television set design. Vacuum cleaners and capacitor-start motors produce significant harmonics and noise, as will be demonstrated in some detail later in this progress report.

While the magnitude of harmonics and noise produced from appliances is low compared to typical line voltage and currents, initial measurements suggest that they can be high with respect to distribution-line power-carrier signals and high with respect to home-communication-system signals. This aspect of the harmonics and noise will be understood better as data are obtained from additional houses.

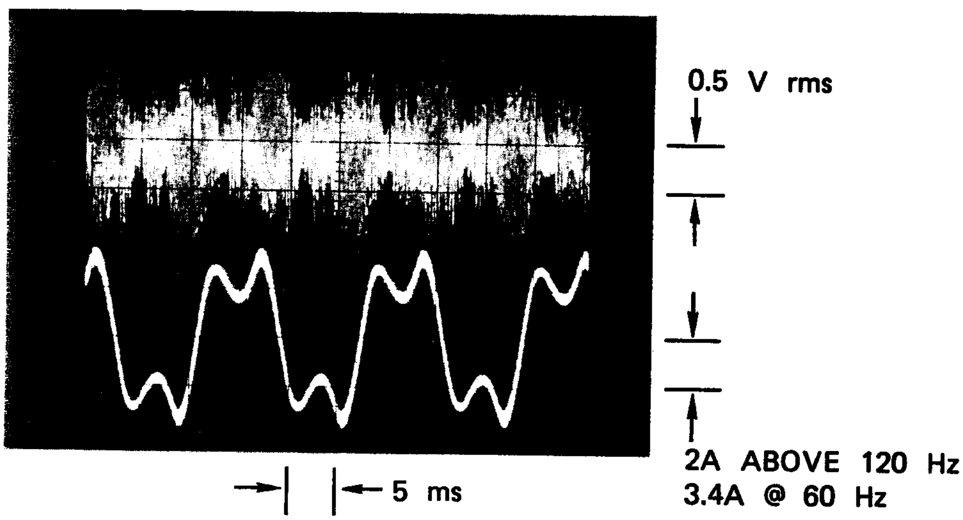
Vacuum Cleaners

Four different types of vacuum cleaners were available in a Los Altos Hills home (LAH1). The gross detail of the voltage and current harmonics and noise were similar for the four units, but the fine scale detail was considerably different for the four vacuum cleaners. Figures 1 through 3 show data from a standard 1/2-hp motor shop vacuum cleaner. The voltage and current waveshapes for unloaded operation are shown on Figure 1. The current waveform was stable and distorted, as shown. The 60-Hz component of the line voltage was removed with a filter to portray the noise structure better at higher frequencies.

Figure 2 shows the time history of the voltage spectral components as the shop vacuum was started. The ambient voltage-harmonic background on the house wiring prevented the examination of low-level harmonics and signals from the shop vacuum cleaner. A distinctive, frequency-varying structure can be seen in the three-axis view as the motor increases in speed. The amplitude of each spectral component can be determined from the upper view. The 60-Hz fundamental and harmonics below 600 Hz were attenuated by the probe to limit signal dynamic range for processing. The amplitude of voltage harmonics below 600 Hz will be determined from additional measured data, which emphasize that range of frequencies.

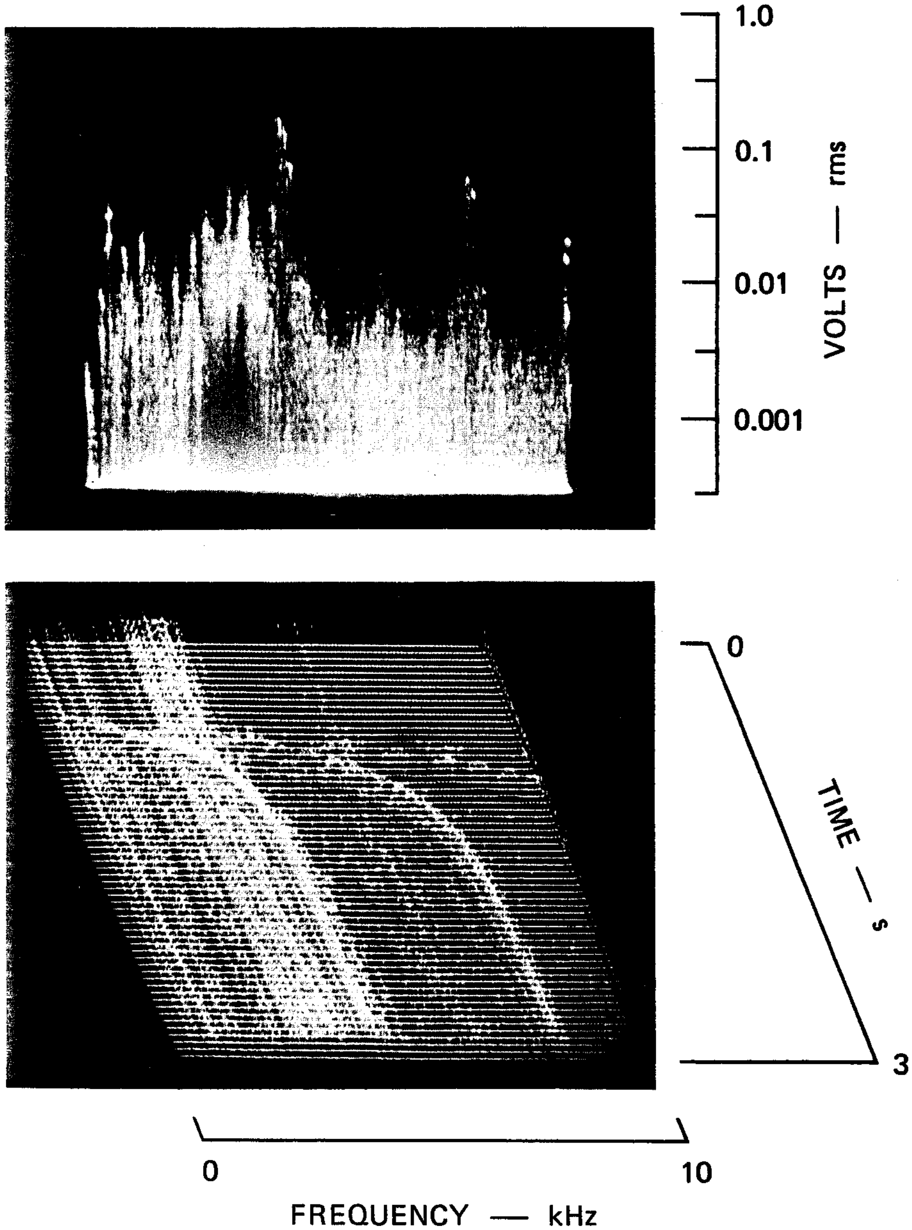
Current harmonics are shown on Figure 3. Frequency-varying spectral peaks found in the voltage-harmonic data also appear in the current data. The current-sensor response was flat from 120 Hz to well above the 10 kHz upper limit of the data in Figure 3. The current harmonic background was low compared to the two peaks. The amplitude of the spectral peaks is shown in the upper view.

The frequency and amplitude of the spectral peaks shown in Figures 2 and 3 changed considerably from one model of vacuum cleaner to another, but the gross detail was similar.



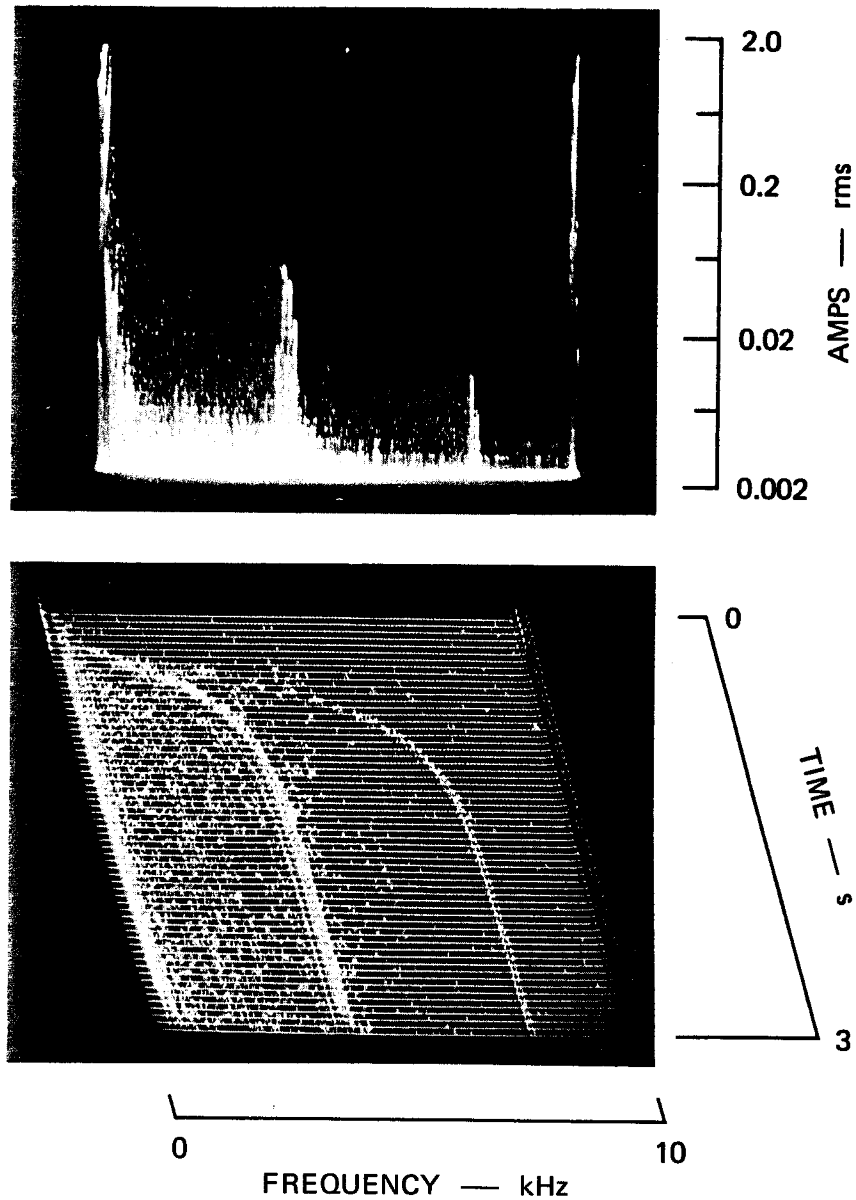
2031, 4-25-83
LAH1, GARAGE, SHOP VACUUM CLEANER
P201D(-20), +20, 0.5 V/cm, 5 ms/cm
CT5, 20/1, 10/1, +20, 0.1 V/cm, 5 ms/cm

FIGURE 1 UNLOADED SHOP VACUUM CLEANER VOLTAGE AND CURRENT WAVEFORMS



2029, 4-25-83
LAH1, GARAGE, SHOP VACUUM CLEANER
V, P201D(-20), +20, -20, +10
0, 10, T10, × 1

FIGURE 2 SHOP VACUUM CLEANER VOLTAGE HARMONICS AND NOISE, 0 TO 10 kHz



2034, 4-25-83
LAH1, GARAGE, SHOP VACUUM CLEANER
CT5, 20/1, 10/1, +20, -10, +10
0, 10, T10, X 1

FIGURE 3 SHOP VACUUM CLEANER CURRENT HARMONICS AND NOISE, 0 TO 10 kHz

Table Saw: Capacitor-Start Motor

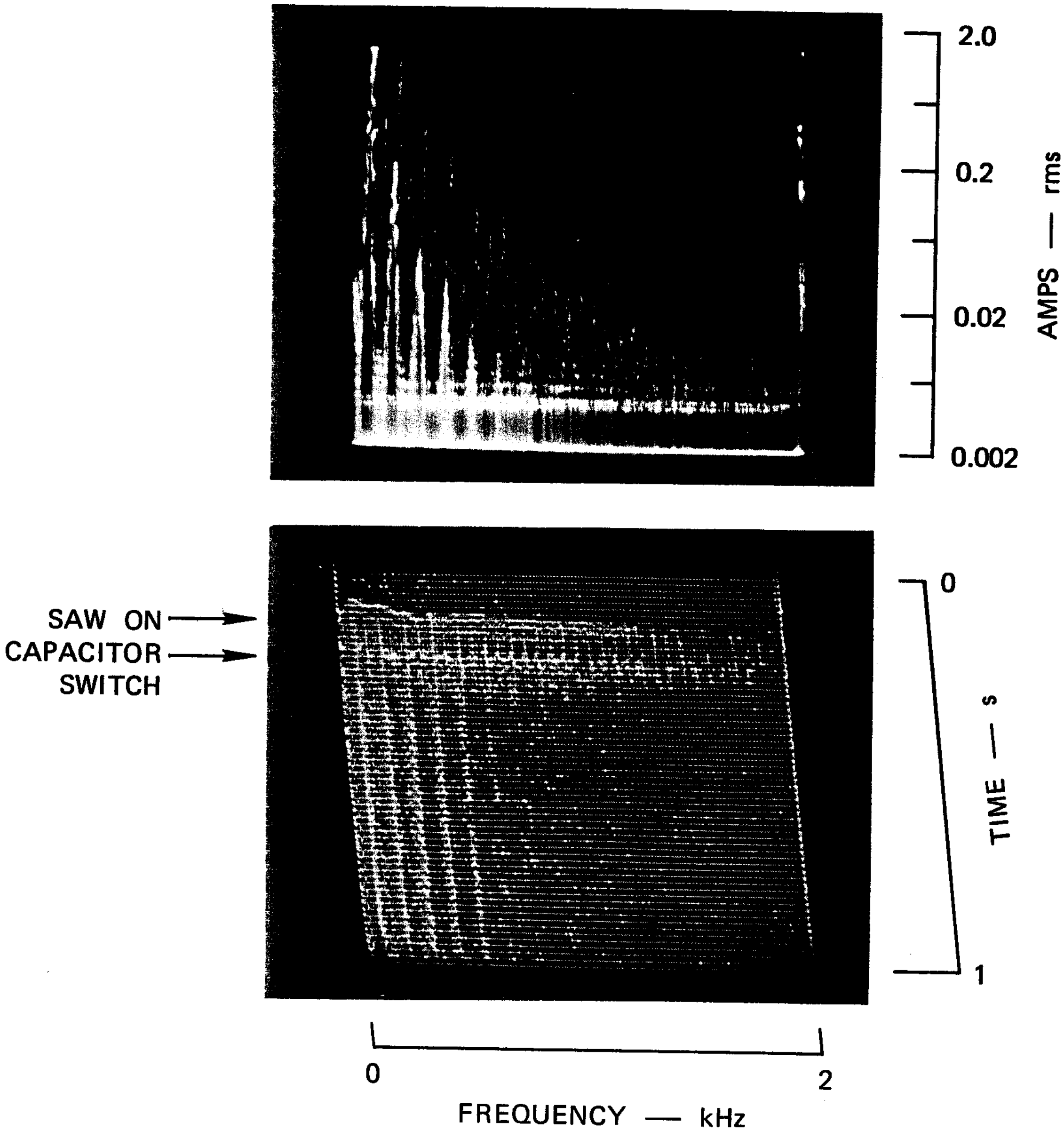
Figure 4 shows the spectral structure of current harmonics as a 1/2-hp capacitor-start table-saw motor was started. The three-axis view shows the initial switching transient followed by a brief period of high current harmonics. High current harmonics were present until a centripetal-force switch removed the starting capacitor from the motor, which generally reduced the higher-order harmonics. A few low-frequency harmonics remained at fairly high current levels. The amplitude of current in each harmonic can be determined from the upper view. The short-term structure appears as a weak background, while the operating harmonic amplitudes are more intense.

Table-saw voltage harmonics were also measured. Figure 5 shows the resulting spectral structure. Ambient voltage harmonics completely dominated the view and prevented the measurement of voltage harmonics from the motor. A switching transient from an unknown source can be seen at the center of the three-axis view. Lower-level voltage transients can be seen throughout the three-axis view.

Ambient voltage-harmonic amplitude at the time of the table-saw motor measurements was slightly higher than the ambient amplitude at the time of the shop vacuum cleaner measurements. The behavior of the ambient harmonic and noise level with time is not understood at this time.

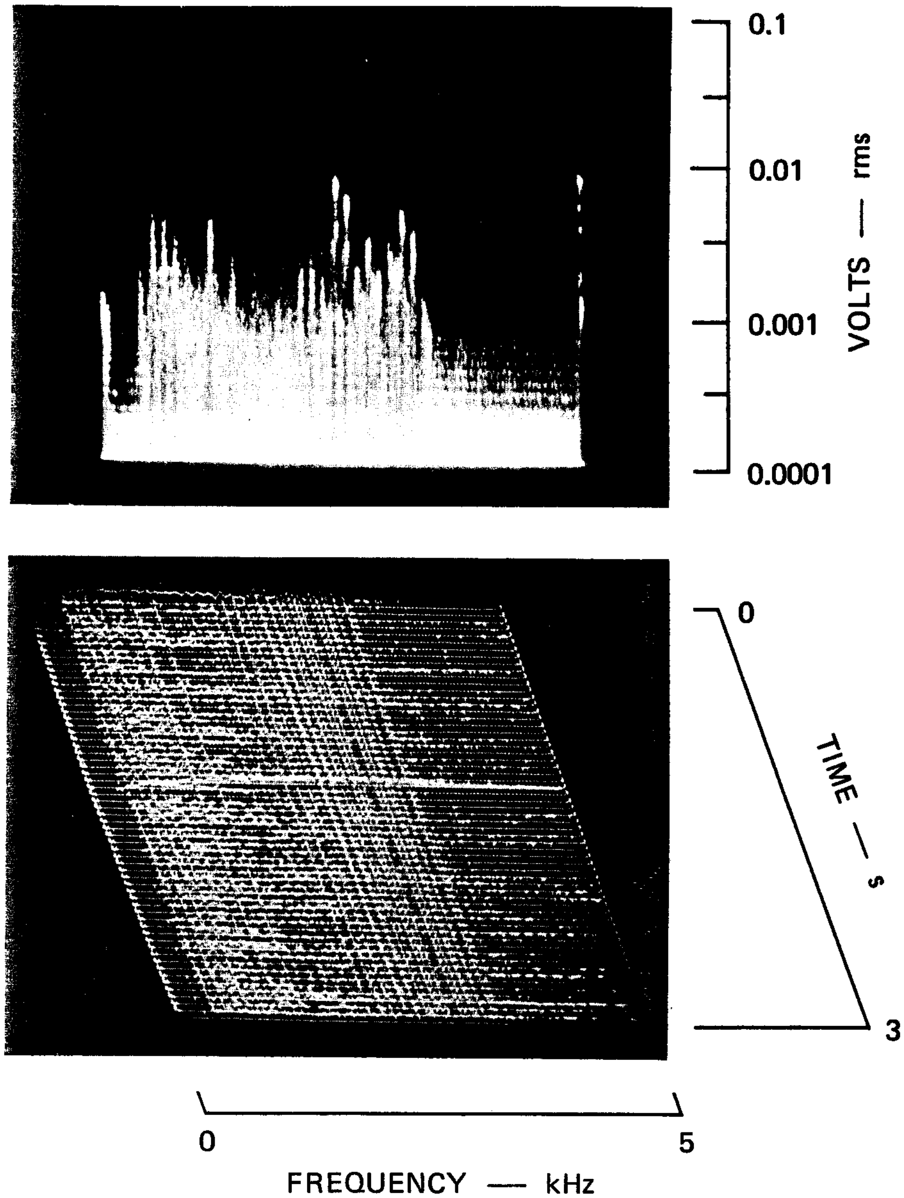
Figure 6 shows spectral sidebands around the 60-Hz fundamental and around the third harmonic of the current. The amplitude of these sidebands was only about 10 dB below the no-load 60-Hz current. Under heavy load, the amplitude of the fundamental increased, while the amplitude of the sidebands decreased sharply. The frequency of the sidebands moved closer to the fundamental and third harmonic components as the load was increased. A small second harmonic component appeared when the motor was under load.

The upper view of Figure 6 shows the amplitude of the structure portrayed in the lower, three-axis view. Notation has been added to the view to show the amplitudes of the fundamental without load and under



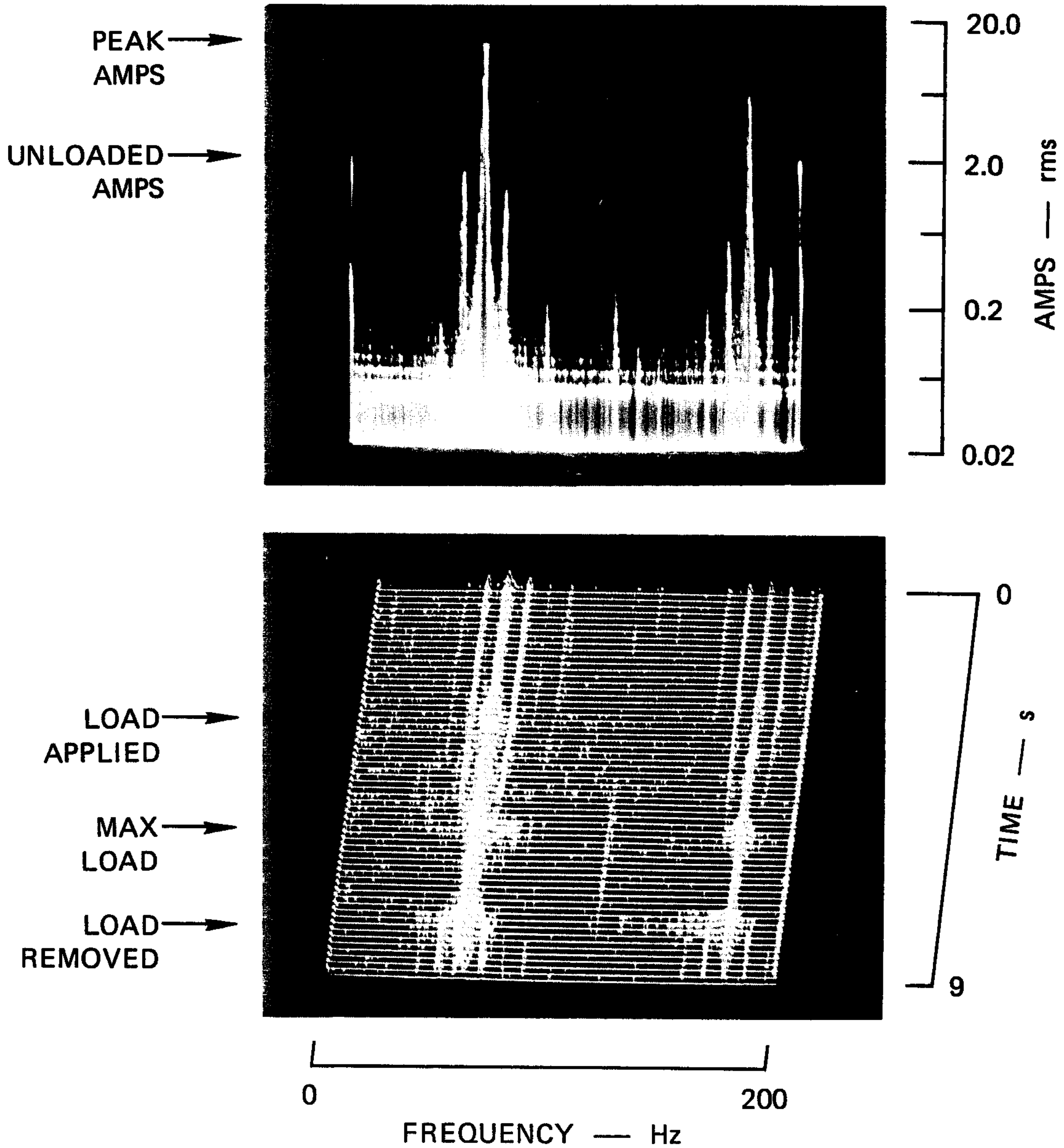
1231, 4-13-83
LAH1, GARAGE, TABLE SAW
I, CT5, 20/1, 10/1, +20, -10, +10
0, 2, T2, X 1

FIGURE 4 TABLE-SAW CURRENT HARMONICS AND NOISE, 0 TO 2 kHz



1245, 4-13-83
LAH1, GARAGE, TABLE SAW
V, P201D(-20), +20, -10, +10
0, 5, T5, X 1

FIGURE 5 TABLE-SAW (AMBIENT) VOLTAGE HARMONICS AND NOISE, 0 TO 5 kHz



1525, 4-12-83
LAH1, GARAGE, TABLE SAW
I, CT5, 20/1, 10/1
0, 200, T200, X 3

FIGURE 6 TABLE-SAW LOADING EFFECTS ON CURRENT HARMONICS AND NOISE, 0 TO 200 Hz

heavy load. Additional data are available to show these variations in amplitude with loading in more detail. Additional table-saw data show sidebands accompanying all prominent harmonics.

As data are obtained from additional houses, the quality and magnitude of harmonics and noise typically produced by home appliances will be discovered. Typical appliance voltage and current noise will then be compared with ambient distribution-line voltage and currents, with distribution-line power-carrier signals, and with home-communication system signals. Throughout the residential measurements project an effort will be made to categorize home appliances according to produced harmonics and noise. The resulting data base of appliance-produced noise, for sufficiently large samples, can be expected to show correlations between noise and appliance design.

Appendix

Description of Data Presentation

Data were processed and formatted by the instrumentation van equipment into two- and three-axis visual views showing spectral and temporal detail of measured harmonics and noise. The data were then recorded with a set of photographs. Measurement and instrumentation parameters particular to each set of data were placed in a small table accompanying each photograph.

For time domain measurements with an oscilloscope, the table parameters are:

- Line 1--Local time of measurement, date of measure.
- Line 2--Measurement location number, measurement site, measured appliance.
- Lines 3 and 4--Sensor or probe, line amplifier gain, oscilloscope gain, oscilloscope sweep speed.

Figure 1, for example, identifies the measurement location number as the first home in Los Altos Hills (LAH 1), the measurement site as the garage, and the measured appliance as a shop vacuum cleaner.

For measurements with a channelized analyzer (Nicolet UA500) and three-axis display (Figures 2 to 6) the table parameters are:

- Line 1--Local time of measurement, date of measurement.
- Line 2--Organization code, measurement site, measurement location number, test voltage.
- Line 3--Sensor or probe, line amplifier gain, analyzer input attenuation, analyzer output gain.
- Line 4--Start frequency, stop frequency, terminate frequency, time axis expansion factor.

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EPRI EL/EM-4290
Volume 1
Project 2017-1
Final Report
October 1985

Harmonics and Electrical Noise in Distribution Systems

Volume 1: Measurements and Analyses

Prepared by
SRI International
Menlo Park, California

of these harmonics were customer switching devices and nonlinear loads. In no case did utility-generated harmonics limit the performance of a DLC receiver.

• Gap noise occurred on distribution lines at all utilities. Gap noise could be a significant source of interference to communication and radio services using frequencies from 30 kHz–500 MHz.

• Signals from a DLC system operating on a distribution line appeared on other distribution lines operating from the same substation and on distribution lines from other substations connected by a common transmission line.

• Some customer communication systems whose operating frequencies were within the range used by DLC systems (1–15 kHz) used utility distribution lines to propagate signals from one location to another. Although no case of direct interference was found on either utility DLC systems or customer-operated systems using the same frequency, significant expansion of DLC systems could eventually result in utility-customer conflicts for operating frequencies and in serious interference to DLC systems.

EPRI PERSPECTIVE

Both the utility industry and equipment manufacturers will find the study results and data useful. Utilities can use the data to develop mitigation techniques such as filtering and shielding to minimize harmonics and noise carried by distribution systems. The report will give manufacturers of high-power switching equipment a better understanding of the need to reduce harmonics generated by their equipment. Standards committees such as the American National Standards Institute and EEI can use these results as guidelines for developing new standards to protect both utilities and their customers from electrical noise interference.

PROJECT

RP2017-1
EPRI Project Manager: William Shula
Electrical Systems Division; Energy Management and Utilization Division
Contractor: SRI International

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Harmonics and Electrical Noise in Distribution Systems
Volume 1: Measurements and Analyses

EL/EM-4290, Volume 1
Research Project 2017-1

Final Report, October 1985

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Menlo Park, California

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ABSTRACT

Conducted and radiated electrical noise associated with more than 100 distribution feeders of ten utilities located throughout the United States were examined. Noise and harmonics that could interfere with distribution-line carrier systems were measured at frequencies from 10 Hz up to above 30 kHz. These included conducted voltage and current measurements and the near zone measurement of electric and magnetic fields. Additional harmonic and noise measurements were made over the frequency range of 10 Hz to 1 GHz. The amplitude, spectral, and temporal properties of harmonics and noise are presented.

The noise on feeders was divided into distinct types (subfundamental noise, synchronuous impulsive noise, random impulsive noise, customer appliance generated noise, gap noise and transients). The temporal and spectral characteristics of each type of noise were determined. These characteristics, and the sources of harmonics and noise, changed considerably over the frequency range investigated. Sources for each type of noise were identified, and dominant sources included SCR and related switching devices, induction motors, universal wound motors, television sets, and electrical breakdown of distribution line pole hardware.

The dominant type of noise conducted along feeders at distribution-line carrier frequenies (1 to 15 kHz) is synchronous impulsive noise. The synchronous impulses produce harmonics in the frequency domain. The primary sources of these impulses (and their harmonics) are line-synchronous switching devices, electronic load control equipment, and other devices operated by customers.

Because of the very large variation in amplitude of harmonics and noise from location to location (both voltage and current), and because of frequent abrupt changes in harmonic and noise amplitudes with time at a fixed location (changes in amplitude of 10 to more than 30 dB were common), conventional statistical measures of amplitude do not adaquetly describe harmonic and noise levels in utility distribution systems. Nonstationary conditions were dominant and nonstationary means to describe harmonic and noise amplitudes are necessary.

Measurement techniques and equipment used for the project are described. Recommendations are made for utilities and for manufacturers of equipment that produce harmonics and noise.

ACKNOWLEDGMENTS

Several people have contributed to the material contained in this report, to the writing of the report, and to the review of data, figures, and text. The effort to produce the report has taken more than four years, and the data collected during that long period were extensive.

Dr. William Blair of EPRI directed the overall effort and contributed greatly to the conduct of the work and to the technical review of data and results. My collegues at SRI International aided considerably in the conduct of the work and the preparation of this report. Significant contributions were made by Mr. Robert Bollen, Mr. Billy Ficklin, Ms. Jane Clemmensen, Mr. John Meloy, and Mr. Ralph Evans of the Radio Physics Laboratory of SRI International. The effort could not have been completed without the cooperation and assistance of a number of electric utilities located through the United States. Each utility appointed a coordinator to provide support and assistance and to participate in making the measurements. The aid of these coordinators was essential, and they were supported by numerous other managers and employees of the utilities involved. The coordinators for the main portion of the effort that is contained in this report were

Mr. David Sharer	Pacific Gas & Electric Company
Mr. H. E. (Bud) Wegner	San Diego Gas & Electric
Dr. Merwin Brown	Arizona Public Service Company
Mr. John McCoy	Texas Electric Service Company
Mr. Robert Archibald	Public Service Electric & Gas Company
Mr. Agit Kadakia	South Central Power Company
Mr. Donald Hay	Detroit Edison
Mr. Gary Michel	Florida Power & Light Company
Mr. Louis Gale	Carolina Power & Light Company
Mr. Lee Worrel	Virginia Electric Power Company

These individuals aided significantly in the completion of work at their respective utilities. They helped the measurement crew become familiar with their utility, and the areas covered by their utility, and they assisted in the many details necessary for the successful completion of the measurements. They made the visit to each utility easy, pleasant and successful.

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TABLES

SUMMARY

A large-scale measurement was made of radio noise that is associated with distribution systems of the electric utilities. Harmonics and electrical noise was measured on more than 100 distribution lines that were operated by ten electric utilities. Utility locations were selected from all sections of the country, and the lines measured included those serving customers in urban (heavy industrial), suburban(commercial, residential), and rural (argricutural) regions.

The project emphasized the measurement of radio noise on distribution lines at frequencies used by distribution-line carrier systems. These systems employ distribution lines to conduct communication signals between a terminal located in a substation and a large number remote terminals. The remote terminals can be used for reading watt-hour meters (particularly hard-to-read locations), controlling capacitors, distribution-line switching tasks, regulator switching, full-service disconnects, load surveys, location of faulted sections, and other purposes. The frequencies used by such systems are usually in the range of 1 to 15 kHz.

Additional measurements were made of conducted and radiated noise over the total freqency range from 10 Hz to above 1000 MHz. Thus, all types of noise associated with distribution lines were examined. For convienence in describing the primary properties of measured noise, the types encountered were placed into categories. These categories included (1) subfundamental signals and noise, (2) harmonics (3) synchronous impulsive noise, (4) gap noise, and (5) noise from insulator leakage. Spectral and temporal signatures were developed for each type of noise. Sources for each type of noise were identified.

Subfundamental signals were identified on a number of distribution lines. The source of subfundamental signals was usually from a customer-operated load-control device employing a line-synchronous frequency divider to trigger an SCR device.

At frequencies used by distribution-line carrier systems, the dominant noise was from synchronous impulsive noise originating from switching devices operated by customers. Measurements of this type of noise were usually made in the frequency domain where it appeared as harmonics of the power-line frequency.

Synchronous impulsive noise was found on almost all distribution lines. The frequency range extended from 120 Hz to well above 1 MHz. This type of noise could be described in either the time domain as an impulsive noise or on the frequency domain as harmonics of the line frequency. The instrumentation permitted measuring harmonics up to 30 MHz (harmonic No. 300,000). A number of sources of this type of noise were identified; all of which were associated with customer-operated switching devices.

At frequencies from 30 kHz to above 300 MHz, gap noise was the dominant type of noise. Gap noise produced a distinctive temporal signature containing a series of closely spaced impulses that were all identical in amplitude. This permitted the rapid identification of gap noise during field measurements. At frequencies below about 2 or 3 MHz, gap noise was conducted along distribution lines for several pole spans. At higher frequencies, gap noise was radiated from metal hardware connected to or near the source.

Insulator leakage on distribution lines was not a significant source of noise. It is included in the report because of the popular belief that insulator leakage is a large source of noise. All cases of suspected insulator-leakage noise investigated during the measurements were identified as gap noise.

During the measurements, a number of communication signals were found on distribution lines that originated from communications systems operated by customers. The utilities generally were unaware that their lines were being used by customers for communication. These systems use the same band of frequencies that are used for distribution-line carrier systems, and the signals will become a severe source of interference as distribution- line carrier networks are expanded. The utilities should seek regulatory protection to control communication signals and noise injected into their lines and to reserve this signal propagation resource (that is owned by the utilities) for their own purposes.

Considerable difficulty was experienced in describing harmonic and noise levels with common statistical measures of amplitude such as average, root-mean-squared, peak, or quasi-peak amplitude. This was due to the large number of voltage and current harmonics involved, the very large variations in amplitude of one harmonic to other nearby harmonics, the non-flat spectral characteristics of harmonics and noise, and even more important, due to abrupt large changes in amplitude of 10 to more than 30 dB. These frequent, abrupt, and large changes in amplitude were nonstationary in character, and nonstationary descriptors of amplitude were found to be necessary to fully describe harmonics and noise conditions on distribution systems.

It is intended that the data and results contained in this report be available to several sectors of the electrical utility industry. The utilities can use the data to develop and implement mitigation procedures and techniques to minimize harmonics, noise, and signals carried by distribution systems. The manufacturers of switching devices, load control equipment, and consumer products can better understand the need for lowering the level of harmonics, noise, and signals that are fed back into distribution systems. The manufacturers of computers and electronic equipment that are now sensitive to harmonics, noise, and signals on the distribution system can design products that are less sensitive to these factors. Standards committees can use the results as guidlines for new and revised standards to protect utility customers from undue difficulty from harmonics, noise, and signals on their feeders.

Section 1

INTRODUCTION

In this report, results are presented of measurements of harmonics and electrical noise associated with distribution lines used by the electric utilities to deliver electric power to customers. The report covers work accomplished over a period of more than three years, during which measurements were taken at a total of 10 electric utilities located throughout the United States. Understanding the type and sources of noise that would limit the performance of distribution-line carrier (DLC) systems was emphasized.

Measurements and studies on operating distribution systems covered a very wide range of technical areas; a very large amount of data was collected and analyzed. Conducted and radiated measurements were taken at the 10 utilities selected for examination on more than 100 distribution lines. Each distribution line selected for measurement was examined at a number of locations along the line from the distribution substation to the end of each line. Whenever possible, distribution lines that contained DLC signals were chosen so that signal amplitude, noise amplitude, and signal-to-noise ratio could be determined.

A number of supplementary tasks were added to the project at various times during the performance period. These tasks included measuring conducted and radiated noise that is associated with advanced power generation and conversion techniques and with noise that is associated with the electrical wiring in homes. Separate technical memoranda were published that describe the results of these added tasks; therefore, only brief summaries of these added tasks are provided in this report.

The report is an integrated presentation of the distribution-line measurements. Section 2 contains the objectives of the project. Section 3 has a brief description of the instrumentation employed for field measurements. A document that contains a more comprehensive description of the instrumentation is referenced in Section 3. Section 4 provides a very brief summary of the measurements completed at each utility. A list of the supplementary measurements is in Section 4, and a brief summary of each supplementary is provided in Appendix A. Section 5 contains a comprehensive presentation of the results of conducted and radiated measurements on distribution lines at all utilities. Section 5 also presents data from the measurement of DLC signals and contains descriptions of the factors that limit the performance of DLC systems. Section 6 presents the overall findings of the measurements on distribution lines. This section does not contain the findings for the supplementary measurements; they are in the technical memoranda published for the supplementary measurements. Section 7 provides overall recommendations to EPRI and to the utilities on methods to mitigate harmonics and electrical noise in the distribution system, and to improve the performance of DLC systems. Section 8 lists the conclusions of the work, and Section 9 provides specific recommendations to EPRI and the utilities for future investigations.

The primary technical aspects of the measurements on distribution lines are provided in Section 5. The results of measurements at all utilities are integrated into a comprehensive presentation of conducted and radiated electrical and radio noise. The integrated presentation of measured data and of the results of the measurements were found the most effective means of showing the wide variety of technical effects noted during the field work. The alternate approach of presenting a detailed review of results obtained at each utility would have resulted in a fragrmented presentation, the duplication of much data, and an extremely unwieldy document.

Section 2

OBJECTIVES

The objectives of EPRI Project 2017-1 were broad and comprehensive. They are summarized as follows:

(A) To develop an instrumentation system to measure and define the primary spectral, temporal, and spatial properties of conducted and radiated electrical and radio noise associated with electric utility distribution lines.

(B) To measure the primary properties of conducted and radiated electrical and radio noise associated with distribution lines at a number of electric utilities located throughout the United States.

(C) To analayze measured data obtained at a number of utilities to determine if technical properties of electrical and radio noise are similar or dissimilar throughout the nation.

(D) To obtain data on the technical characteristics of noise that might affect the performance of DLC systems.

(E) To examine DLC signals on distribution lines at both substation terminals and at remote terminals, and to relate the signal amplitudes to the background noise levels at typical locations at which the performance is poor.

(F) To investigate the causes of performance limitations in DLC systems.

(G) To identify the sources of electrical noise that limit the performance of DLC systems.

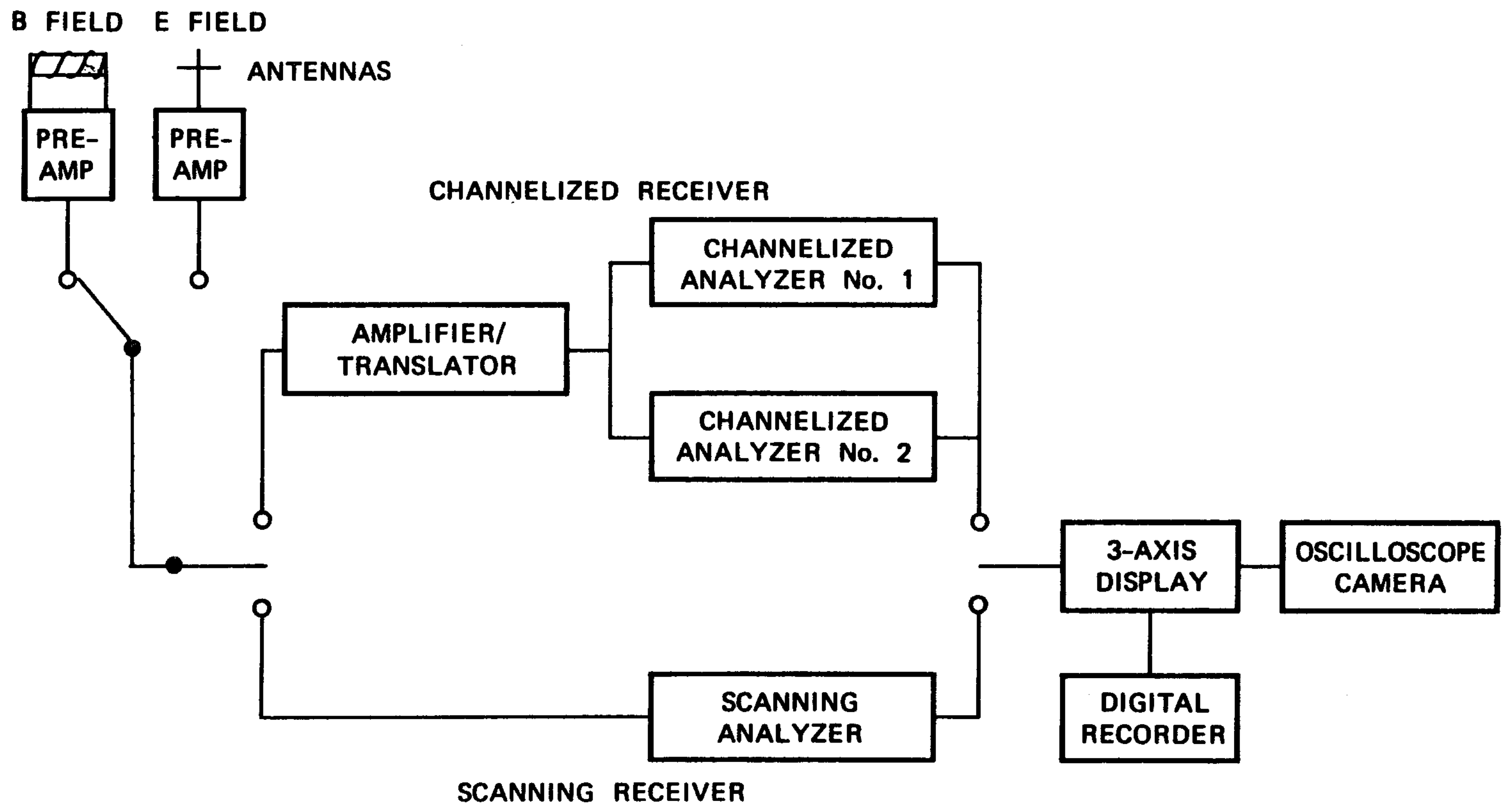

Figure 3-1. Simplified Block Diagram of Instrumentation

The HP140 scanning spectrum analyzer was usually operated with a Model 8553B RF head and a Model 8552B IF section. These standard plug-in sections provided a frequency-analysis range of about 3 kHz to 1250 MHz. This frequency range was adaquate for most measurement and analysis situtations. The analyzer controls were set to values that best defined the signals or noise under examination. The scan-time control of the scanning receiver was usually set at a value that permitted the display of several successive periods of the power line frequency on each scan of the analyzer (a 100-ms analyzer scan time displayed six periods of a 60-Hz frequency on each scan). The accumulation of successive analyzer scans on the 3-axis display permitted the scan-time feature of the analyzer to portray the temporal properties of signal or noise components that were synchronous with the power-line frequency. Normally, a scanning analyzer is not used to define the temporal properties of signals and noise because of the inability to observe temporal data on the 2-axis display of an analyzer display.

Changes in the temporal or spectral structure of signals or of noise were immediately shown on the 3-axis display. The operator had a complete, calibrated, time-memory view of all signals or noise under observation. Instrumentation parameters could be changed in real-time to define the spectral and temporal detail of displayed signals. This feature was of special value for analyzing time-variable signals, impulsive signals, and noise, including nonstationery signals and noise.

Several sets of electric- and magnetic-field sensors were available for measuring electromagnetic fields in either the near or distant zones. In the near zone of a signal or noise source, both the electric field and the magnetic field were measured to provide a complete description of the electromagnetic field. In this zone, the electric field of a source is related to the voltage between the source and ground, and the magnetic field is related to the current flowing in a conductor. In the near zone of a source, the electric field cannot be related to the magnetic field by free-space impedance (120 pi). When signals from distant sources were received by the sensors, the electric field and magnetic field were related by free-space impedance.

Magnetic fields at frequencies from 60 Hz to 300 kHz were measured with a Model B101 sensor. The amplitude-versus-frequency response of this sensor was flat from 1 kHz to 300 kHz. Above 300 kHz, the response was attenuated to avoid strong unwanted signals when operating near broadcast stations. Below 1 kHz, sensor response was deemphasized to measure low-level magnetic fields at DLC frequencies in the presence of strong fields at 60 Hz and low-order harmonics of 60 Hz. Other experimental sensors were used to measure magnetic fields at frequencies above 300 kHz.

Electric fields at frequencies from 60 Hz to above 300 kHz were measured with a Model E101A sensor. The amplitude-versus-frequency response of this sensor were similar to that of the magnetic-field sensor. A 1-m rod antenna was used to measure electric fields at higher frequencies.

The electric- and magnetic-field sensors could be replaced by

Section 3

INSTRUMENTAION

3.1 GENERAL APPROACH

The measurement and analysis tasks defined by EPRI required that an instrumentation system be provided that could define a wide variety of signal and noise situtations. The frequency range desired extended from 10 Hz to about 1000 MHz. The dynamic range of signals and noise was expected to be as large as 80 dB. Detailed spectral, temporal, and spatial data were desired in order to define the characteristics of discrete-frequency signals, wideband noise, and combinations of the discrete-frequency signals and wideband noise. In addition, all data had to be defined in basic electromagnetic units so that they could be compared with other data.

An examination of EPRI requirements suggested that three basic types of measurements were required:

(A) The measurement and definition of discrete frequency signals and broad-band noise (both voltage and current) on conductors.

(B) The measurement and definition of electromagnetic fields in the near or inductive region of a source.

(C) The measurement and definition of electromagnetic fields in the distant zone of a source.

An instrumentation system had already been developed that met the general requirements of the EPRI work, and exploratory field measurements had been completed before this project was started. This background permitted implementing the EPRI work immediately without incurring the cost and time to develop a suitable instrumentation system.

This section provides a general description of the instrumentation system used for the project. A more comprehensive description is provided in a separate technical memorandum [1]*.

* References are listed at the end of this report.

3.3 GENERAL DESCRIPTION

Figure 3-1 shows a simplified block diagram of the measurement system, and the primary components of the system are identified in the block diagram. The basic system consists of electric- and magnetic-field sensors, directly connected voltage and current probes, two channelized spectrum analyzers; a scanning spectrum analyzer; a 3-axis display; and the auxiliary items needed to integrate the individual instruments into a complete measurement system.

Complementary, signal-processing channels are used in the instrumentation system. The channelized analyzers provide a means to analyze signals and noise with high frequency-domain resolution. Only modest time-domain resolution is obtained with the channelized analyzers. The scanning analyzer combined with the 3-axis display provide a means of analyzing the same signals or noise with high time-domain resolution and only modest frequency-domain resolution. These two signal-processing channels (channelized and scanning) permit the operator of the instrumentation system to obtain detailed information about the spectral and temporal characteristics of signals or noise.

Two types of channelized analyzers are used in the measurement system. An Hewlett-Packard Model 3582A analyzer provides a high dynamic range for the analysis of signals and noise in frequency bands up to 25 kHz wide. The model 3582A analyzer, however, has poor time-domain resolution (operating at a maximum of 2 spectra/s). This analyzer provides an excellent means of analyzing signals that are stable in time, but it provides only a limited capability to analyze signals that vary with time. A Nicolet Model UA500A analyzer is also used in the measurement system. The UA500A analyzer provides modest dynamic range for frequency bands up to 100 kHz wide. This analyzer has a much higher spectral analysis rate than the HP analyzer, and it is useful for the analysis of time-varying signals and transients. The UA500A analyzer combined with the 3-axis display provide an effective means of analyzing time-varying signals and transients.

A Develco Model 7200B 3-Axis Display is used with the HP140 scanning analyzer and with the UA500A analyzer. A switch enables the system operator to connect the 3-axis display to either analyzer. The display is fully controlled by the analyzer selected and provides a time history of all signals and noise processed by the connected analyzer.

The channelized analyzers can be operated at baseband analyzing low-frequency signals (0 to 25 kHz for the HP3582A and 0 to 100 kHz for the Nicolet UA500A). A linear frequency translator (a single-sideband receiver operating in the upper sideband mode is an excellent frequency translator) can be used to obtain high spectral resolution for the analysis of signals above the baseband frequency range. The use of a linear translator with the channelized analysers provided a total frequency analysis range from dc up to 30 MHz for the channelized analyzers.